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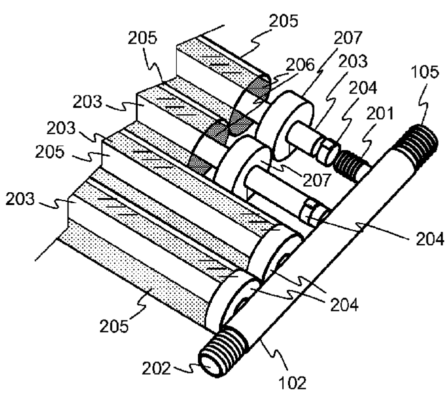

FIG. 2

(57) Abstract: A solar collector is made primarily of plastic materials. A wide variety of collector configurations may be made from similar parts, and thus the collector may be adapted to mount in locations where traditional flat panel collectors may not be feasible. The collector may conveniently be used with a nanofluid as the heat transfer fluid, to increase the heat transfer characteristics of the heat transfer fluid. A control system for stagnation remediation, freeze protection, or both may be utilized. For example, when the collector is in danger for stagnation or freezing, water may be circulated through a ground coupled heat exchange loop to cool or heat the collector. Preferably, the stagnation remediation mode does not sacrifice thermal energy previously collected and stored.

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SOLAR COLLECTOR

BACKGROUND OF THE INVENTION

[0001] Sunlight provides a source of renewable, clean, and freely available energy useful in a variety of applications, including water heating, space heating, electricity generation, and other areas. Devices for collecting and concentrating solar energy have been developed to take advantage of the ready availability of this energy source. For example, flat panel collectors are often used in low temperature applications such as space heating and domestic water heating. Concentrating collectors may be used in higher temperature applications such as electric power generation, industrial process heating, and other applications.

[0002] Conventional flat panel collectors have a number of disadvantages. For example, they are typically made of relatively expensive materials such as copper, aluminum, and glass due to requirements for strength and thermal conductivity. Flat panel collectors are also typically provided in relatively large form factors, for example up to four by eight feet, and thus may be difficult to integrate into architectural designs.

BRIEF SUMMARY OF THE INVENTION

[0003] According to one aspect, a solar energy collector comprises an elongate plastic receiving tube configured to carry a heat transfer fluid, and an elongate clear plastic tubular sheath surrounding the receiving tube. The sheath is of a larger cross section than the receiving tube such that a generally annular air space is formed between the receiving tube and the sheath. The sheath has a front side configured to be disposed toward the sun and a back side opposite the front side. The solar energy collector further includes a reflective coating partially covering a portion of the inside surface of the tubular sheath at the back side of the tubular sheath and configured such that when sunlight is directed at the front side of the sheath, a first portion of the sunlight transmitted through the sheath strikes the receiving tube directly, and a second portion of the sunlight transmitted through the sheath strikes the reflective coating and is redirected to the receiving tube. In some embodiments, the receiving tube is made of black polyethylene tubing. The sheath may be made of clear polycarbonate tubing. In some embodiments, both the receiving tube and the sheath have circular cross sections.

[0004] According to another aspect, a solar energy collector includes a plurality of elongate plastic receiving tubes configured to carry a heat transfer fluid. The solar energy collector also includes a plurality of elongate clear plastic tubular sheaths, each sheath surrounding a respective one of the plurality of receiving tubes, each sheath being of a larger cross section than its respective receiving tube such that a generally annular air space is formed between sheath and the receiving tube. Each sheath has a front side configured to be disposed toward the sun and a back side opposite the front side. A portion of the interior surface of the sheath at the back side is covered by a reflective coating configured such that when sunlight is directed to the uncoated portion of the sheath, a first portion of the sunlight transmitted through the sheath strikes the receiving tube directly and second portion of the sunlight transmitted through the sheath strikes the reflective coating and is redirected to the receiving tube. The solar energy collector further includes an inlet manifold including an inlet opening for receiving the heat transfer fluid to be heated and a plurality of outlet openings, and an outlet manifold including a plurality of inlet openings and an outlet opening. Each of the plurality of receiving tubes is coupled between one of the plurality of outlet openings of the inlet manifold and one of the plurality of inlet openings of the outlet manifold. In some embodiments, the inlet and outlet manifolds are made of plastic. In some embodiments, the plurality of receiving tubes are disposed parallel to each other to form a rectangular collector unit. In some embodiments, the inlet manifold, the outlet manifold, the plurality of receiving tubes, and the plurality of sheaths are comprised in a first collector unit, and the solar energy collector comprises one or more additional collector units of like construction to the first collector unit, the inlet manifolds of the one or more additional collector units operatively coupled to the inlet manifold of the first collector unit and the outlet manifolds of the one or more additional collector units operatively coupled to the outlet manifold of the first collector unit. In some embodiments, gaps exist between adjacent members of the plurality of sheaths. The solar energy collector may have an aspect ratio of at least 3:1. The solar energy collector may have an aspect ratio of at least 5:1.

[0005] According to another aspect, a solar energy collection system includes a solar energy collector comprising an elongate plastic receiving tube surrounded by an elongate clear plastic sheath. The sheath is of a larger cross section than the receiving tube such that a generally annular air space is formed between the receiving tube and the sheath. The sheath has a front side configured to be disposed toward the sun and a back side opposite the front side and a reflective coating partially covering a portion of the inside surface of the tubular sheath at the back side such that when sunlight is directed at the front side of the sheath, a first portion of the sunlight transmitted through the sheath strikes the receiving tube directly, and a second portion of the sunlight transmitted through the sheath strikes the reflective coating and is redirected to the receiving tube. The solar energy collection system further includes a supply of the heat transfer fluid to be heated by the solar energy collector. In some embodiments, the solar energy collector comprises a plurality of elongate plastic receiving tubes, each surrounded by a respective elongate clear plastic sheath, the plurality of sheaths and receiving tubes are arranged in parallel such that the solar energy collector is rectangular, and the solar energy collector comprises an inlet manifold and an outlet manifold to direct the heat transfer fluid through the parallel receiving tubes. The heat transfer fluid may be water comprising nanoparticles. The solar energy collection system may further include an ion generator to generate the nanoparticles. In some embodiments, the solar energy collection system further includes a tank for holding the supply of heat transfer fluid, a supply pipe for carrying heat transfer fluid from the tank to the solar energy collector, a return pipe for carrying the heat transfer fluid from the solar energy collector to the tank, a circulation pump for circulating the heat transfer fluid between the solar energy collector and the tank through the supply pile and the return pipe, and a controller that controls the operation of the circulation pump based at least in part on the temperature of the heat transfer fluid in the tank and the temperature of the solar energy collector. The controller may be configured to determine when the solar energy collector reaches a stagnation condition and in response to the determination, enter a stagnation remediation mode. In some embodiments, the solar energy collection system further includes a source of cooling fluid, wherein during the stagnation remediation mode, the cooling fluid is circulated through the solar energy collector without passing through the tank. In some embodiments, the solar energy collection system further includes a ground coupled heat exchanger, wherein in the stagnation remediation mode, the cooling fluid is circulated through the solar energy collector and the ground coupled heat exchanger without passing through the tank. In some embodiments, the ground coupled heat exchanger comprises a piping loop connected between the supply pipe and the return pipe, and the system further comprises a set of valves operated by the controller to isolate the tank during the stagnation remediation mode. In some embodiments, the solar energy collection system further includes a photovoltaic panel that supplies power to operate the controller and the circulation pump. In some embodiments, the solar energy collection system further includes a root zone heating loop, wherein the system circulates the heat transfer fluid through the root zone heating loop to heat the root zone of plants.

[0006] According to another aspect, a method of collecting solar energy includes providing a solar energy collector. The solar energy collector includes one or more elongate plastic receiving tubes each surrounded by a respective elongate clear plastic sheath. Each respective sheath is of a larger cross section than its respective receiving tube such that a generally annular air space is formed between the receiving tube and the sheath, the sheath having a front side configured to be disposed toward the sun and a back side opposite the front side and a reflective coating partially covering a portion of the inside surface of the tubular sheath at the back side such that when sunlight is directed at the front side of the sheath, a first portion of the sunlight transmitted through the sheath strikes the receiving tube directly, and a second portion of the sunlight transmitted through the sheath strikes the reflective coating and is redirected to the receiving tube. The method further comprises installing the solar energy collector in a location that receives sunlight, and passing a heat transfer fluid through the solar energy collector to be heated by the sunlight. In some embodiments, the solar energy collector has an aspect ratio of at least 3:1, and installing the solar energy collector in a location that receives sunlight comprises installing the solar energy collector in a location that cannot accommodate a collector of equal area having a significantly smaller aspect ratio. In some embodiments, the solar energy collector has an aspect ratio of at least 5:1, and installing the solar energy collector in a location that receives sunlight comprises installing the solar energy collector in a location that cannot accommodate a collector of equal area having a significantly smaller aspect ratio.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 illustrates a collector unit, in accordance with embodiments of the invention.

[0008] FIG. 2 shows a partially exploded view of one end of the example collector unit of FIG. 2, and illustrates some additional details of the construction of the collector unit of FIG. 1.

[0009] FIG. 3 shows a sectional view of the collector unit of FIG. 1, and illustrates additional aspects of its operation.

[0010] FIG. 4 illustrates other examples of receiving tubes and sheaths according to embodiments of the invention.

[0011] FIG. 5 illustrates combining several collector units like the collector unit of FIG. 1 into a larger collector, in accordance with embodiments of the invention.

[0012] FIG. 6 illustrates a system including an installation of the collector of FIG. 5 on a roof, used for heating water in accordance with embodiments of the invention.

[0013] FIG. 7 illustrates a system for solar heating of domestic hot water, in accordance with embodiments of the invention.

[0014] FIG. 8 illustrates a system that uses a ground coupled heat exchanger to provide cooling fluid to a collector, in accordance with embodiments of the invention.

[0015] FIG. 9 shows a collector in accordance with another embodiment of the invention.

[0016] FIG. 10 illustrates a solar energy collection system adapted for root zone heating, in accordance with embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0017] Embodiments of the invention provide a solar collector made of low-cost, lightweight polymer materials.

[0018] **FIG. 1** illustrates a collector unit **100**, in accordance with embodiments of the invention. Collector unit **100** includes an inlet manifold **101** and an outlet manifold **102**. During use of collector unit **100**, light from the sun **103** falls on collector unit **100**. A heat transfer fluid enters inlet manifold **101** through inlet opening **104**, travels through receiving tubes not visible in FIG. 1, where it is heated by the sun **103**. The heat transfer fluid then exits outlet manifold **102** through outlet opening **105**. Some of the heat transfer fluid may continue through inlet manifold **101** to one or more additional collector units similar to collector unit **100**, as will be described in more detail below.

[0019] **FIG. 2** shows a partially exploded view of one end of example collector unit **100**, including outlet manifold **102**, and illustrates some additional details of the construction of collector unit **100**. Outlet manifold **102** is preferably made of injection molded plastic, for example a polymer such as polycarbonate, nylon, ABS, or another suitable polymer. The polymer may be reinforced, for example with glass fibers. Besides outlet opening **105**, outlet manifold incudes four side tubes **201** (only one of which is visible in FIG. 2), and another end opening **202**. The particular configuration of outlet manifold **102** may also be called a "multi-port tee". Each side tube and the ends of outlet manifold **102** include fittings for joining tubes, caps, or other item. In the example of FIG. 2, simple barb fittings are shown, but other kinds of fittings could be used. For example, outlet manifold **102** could be a 4-outlet, ¾ inch molded flow-through multi-port tee available from Uponor North America of Apple Valley, Minnesota, USA, and having fittings for attaching PEX tubing. Any other suitable kind of manifold may be used, for example a manifold having a different number of openings. In some embodiments, metal manifolds may be used.

[0020] Collector unit **100** also includes four elongate receiving tubes **203**, one for each of side tubes **201**. Although other materials and sizes may be used, receiving tubes **203** may be made of flexible 1/2 inch black polyethylene pipe, which is manufactured in lengths up to hundreds of feet, and is typically packaged in rolls. The black color of the pipe may facilitate absorption of solar energy. Receiving tubes **203** may be connected to outlet manifold **102** in any suitable way, for example using crimp clamps **204** (only two of which are visible in FIG. 2).

[0021] Collector unit **100** further includes four elongate clear plastic tubular sheaths **205**, one surrounding each receiving tube **203**. Sheaths **205** are a form of glazing and may be made, for example, of clear polycarbonate tubing or another suitable material that is transparent to sunlight or nearly so. In the example of FIG. 2, sheaths **205** may have a circular cross section with a diameter of about 1.25 – 1.5 inches, although other sizes may be used in other embodiments. One side of the inside surface of each sheath **205** is coated with a reflective coating **206**. Reflective coating **206** may be made, for example, of an adhesive-backed aluminum foil, aluminized Mylar, or another suitable reflecting material. Insulating spacers **207** may be fitted over receiving tubes **203**, to maintain the spacing of sheaths **205** to their respective receiving tubes **203**, and to provide an insulating function. Insulating spacers **207** may be made, for example, of a urethane foam or another suitable material. While insulating spacers **207** are shown in FIG. 2 only at the ends of sheathes **205**, additional spacers could be placed at other locations along the length of collector unit **100**.

[0022] **FIG. 3** shows a section view of collector unit **100**, and illustrates additional aspects of its operation. As is apparent in FIG. 3, some of sunlight **301** striking clear sheath **205** passes through clear sheath **205** and strikes receiving tube **203** directly. Another portion of the light strikes reflective coating **206** and is redirected to strike receiving tube **203**. The sheaths **205** thus perform multiple functions. They lend structure and stiffness to collector unit **100**, by virtue of their larger diameter than receiving tubes **103**. Sheaths **205** also serve to reduce heat loss from receiving tubes **103**, protecting receiving tubes **103** from breezes that would remove heat, and forming a generally annular air space **302**, which may further insulate receiving tube **103**. In addition, sheaths **105** support reflective coating **206**, which effectively increases the effective collection area of collector unit **100**, as compared to a collector lacking reflective coatings **206**.

[0023] In FIGS. 1-3, receiving tubes **203** and sheaths **205** are shown as circularly cylindrical perfectly co-axial, but this is not a requirement. Tubes and sheaths having other cross sectional shapes may be utilized, for example elliptical, polygonal, or other shapes. For example, a sheath having a parabolic trough shape on its underside may be used. In another example, a shape including an involute of the collector tube may be used. However, in some embodiments cylindrical sheaths may be preferred for simplicity, cost, or other reasons. Polycarbonate tubes designed for protection of fluorescent light bulbs may be used in some embodiments, and are readily available at low cost.

[0024] In FIGS. 2 and 3, the spaces between receiving tubes **203** and sheaths **205** are annular, being the space between two co-axial cylinders, but this is not a requirement, and in other embodiments, the space between the receiving tube and sheath may be only generally annular. The term “generally annular” is intended to encompass the arrangement as shown in FIG. 3, where receiving tubes **203** and sheaths **205** are perfectly cylindrical and perfectly co-axial, such that air space **302** is truly annular in the mathematical sense, but also to encompass spaces defined when the sheaths surround the receiving tubes but are not perfectly co-axial, and spaces defined when the receiving tube, sheath, or both are not cylindrical.

[0025] **FIG. 4** illustrates other examples of receiving tubes **401a-401d** that are surrounded by sheaths **402a-402d**, forming generally annular spaces **403a-403b** between receiving tubes **401a-401d** and sheaths **402a-402d**. Many other arrangements may be used within the scope of the appended claims.

[0026] **FIG. 5** illustrates combining several collector units like collector unit **100** into a larger collector **500**, in accordance with embodiments of the invention. Collector **500** includes three collector units, including collector unit **100**, joined using at their inlet and outlet manifolds. Heat transfer fluid can enter at inlet opening **104**, travel in parallel through the receiving tubes of collector **500**, and exit at outlet opening **105** after having been heated by the sun **103**. Collectors of other desired sizes can be constructed by joining other numbers of collector units **100**. In the embodiment pictured, each collector unit uses receiving tubes and sheaths about four feet long, and spaced about 1.5 inches apart, so that each collector unit **100** is about six inches wide and about four feet long, and collector **500** is about 18 inches wide and about four feet long. Other sizes and spacings may be used as well as other numbers of collector units, to form a collector of any workable size.

[0027] In some embodiments, the width of each sheath is smaller than the spacing between the receiving tubes, so that a gap exists between adjacent sheaths. This gap may allow airflow through the collector, and may reduce the effect of wind on the collector.

[0028] **FIG. 6** illustrates a solar energy collection system **600** including an installation of collector **500** on a roof **601**, used for heating water in accordance with embodiments of the invention. In this simple installation, system **600** heats a supply of heat transfer fluid **602** in tank **603**. Heat transfer fluid **602** is drawn out of tank **603** and pumped by circulation pump **604** through supply pipe **605** to collector **500**. Heat transfer fluid **602** is heated by solar energy in collector **500**, and flows out of collector **500** and back to tank **603** through return pipe **606**. In this example, tank **603**, collector **500**, and the associated piping form a closed system. Heat transfer fluid **602** may be used as a heat reservoir to provide a heat source for thermoelectric power generation, hydronic heating, root zone heating of plants, or for other uses. Pipes **605** and **606**, as well as the manifolds of collector **500** are preferably insulated to avoid heat loss, but no insulation is shown in FIG. 6 for clarity of illustration.

[0029] The use of a heat reservoir of this type for various purposes is discussed in co-pending U.S. Patent Application No. 12/481,745 filed June 10, 2009 and titled "Integrated Energy System for Whole Home or Building", the entire disclosure of which is hereby incorporated by reference herein for all purposes. Other related information may be found in U.S. Patent Application No. 12/481,741 filed June 10, 2009 and titled "Thermoelectric Generator", and U.S. Patent Application No. 12/481,750 filed June 10, 2009 and titled "Automatic Configuration of

Thermoelectric Generation System to Load Requirements”, the entire disclosures of which are hereby incorporated by reference herein for all purposes.

[0030] In one simple mode of operation, a controller **608** receives signals indicating the temperature of heat transfer fluid **602** in tank **603**, and the temperature of collector **500**. If heat transfer fluid **602** in tank **603** is not at its desired temperature, and collector **500** is at a temperature higher than the temperature in tank **603**, controller **602** causes circulation pump **604** to run so that the available energy at collector **500** is used to heat tank **602**. In some embodiments, a photovoltaic panel **612** may be used to power controller **608** and circulation pump **604**.

[0031] In some embodiments, heat transfer fluid **602** is water. Because collector **500** is mounted on roof **601** and exposed to the elements, water in collector **500** could be subjected to freezing temperatures. Preferably, tank **603** is located in a conditioned space, and system **600** operates as a “drain back” system. A volume of air may be included in the system, sufficient to fill collector **500** and the portions of pipes **605** and **606** that are above roof **601** and subject to freezing. When circulation pump **604** is not running, for example when the collector temperature is very low due to cold weather and is lower than the temperature of tank **603**, heat transfer fluid **602** can drain back into tank **603** by the action of gravity, so that collector **500** and the upper portions of pipes **605** and **606** fill with air, and freezing of water in collector **500** is prevented. Preferably, collector **500** is mounted in such a way that corner **609** is the lowest portion of collector **500**, so that heat transfer fluid **602** can drain as completely as possible from collector **500** by gravity.

[0032] Optionally, a vacuum breaker valve may be placed collector **500**, for example at topmost corner **613**, to admit air to collector **500** during drain back, to speed the drain back of heat transfer fluid **602**.

[0033] Traditionally, solar collectors have been made of materials that are highly thermally conductive, for example aluminum and copper, in order to promote the efficient transfer of heat from the collectors to the heat transfer fluid used in them. However, collector **500** is made primarily of plastic materials, which have much lower thermal conductivity than traditional collector materials. For the purposes of this disclosure, to be made primarily of plastic materials means that the receiving, fluid distribution, and glazing components of the collector are made of polymer materials. Some metal parts may be used in a collector that is made primarily of plastic materials, for example for reflective coatings, clamps, mounting hardware, and other incidental functions. The primarily plastic construction of a collector in accordance with embodiments of the invention may afford advantages in material cost, shipping cost, and ease of assembly of the collector. In addition, the light weight of the collector may enable mounting lighter mounting hardware, and mounting the collector in locations that would not support a heavier collector made of traditional materials.

[0034] Even though made primarily of plastic, a model collector made according to an embodiment of the invention has proved surprisingly effective, especially in light of the low cost of its components. For example, a system similar to system **600** was constructed including a collector made the manner shown in FIGS. 1 and 2. The collector included four parallel receiving tubes 20 feet long, and thus had a collecting aperture totaling 10.73 square feet. The system was tested on three sunny days in late winter of 2013 in Longmont, Colorado, to heat water in a tank. Performance was evaluated by measuring the temperature of the tank, operating the collector to heat the tank, again measuring the temperature of the tank, and calculating the amount of energy delivered to the water in the tank from the change in temperature and the mass of water. In three tests on three different days, the system delivered an average of 6684 BTUs of thermal energy to the tank, or 623 BTUs per square foot of collector aperture area. In each test, the system was operated for about 5.5 hours, and the outdoor temperature reached about 57-60 °F.

[0035] The performance of a system embodying the invention can be further improved by enhancing the heat transfer characteristics of heat transfer fluid **602**. One especially effective and economical technique for enhancing the thermal conductivity and convective heat transfer characteristics of water is to convert the water to a nanofluid having suspended nanoparticles. Techniques for generating nanoparticles in water are described in co-pending U.S. Patent Application No. 13/035,479 filed February 25, 2011 and titled “Thermoelectric Generator Using Nanofluid”, and U.S. Provisional Patent Application No. 61/680,671 filed August 7, 2012 and titled “Efficient Energy Collection and Distribution”, the entire disclosures of which are hereby incorporated by reference herein for all purposes.

[0036] In one embodiment as illustrated in FIG. 6, an ion generator **610** includes two sterling silver electrodes **611** that are suspended in heat transfer fluid **602**. Electrodes **611** may be positioned in tank **603**, in one of pipes **605** and **606**, or at another convenient location in the system. It may be advantageous to place the electrodes at a location where heat transfer fluid **602** flows regularly. Ion generator **610** contains circuitry that impresses an alternating voltage between the two electrodes, causing the electrodes to shed ions by electrolytic action. The ions are nanoparticles. The flow of heat transfer fluid **602** distributes the nanoparticles throughout the system. The presence of nanoparticles significantly enhances the heat transfer characteristics of the water, and therefore improves the performance of the system.

[0037] The test results described above for the model system were obtained using pure water as the heat transfer fluid. The same system was tested again with the addition of nanoparticles, and its performance improved significantly. The system was operated in the same manner as described above, on three sunny days in late winter of 2013 in Longmont, Colorado. When operated using water including nanoparticles as the heat transfer fluid, the system delivered an average of 8672 BTUs to the tank, or 808 BTUs per square foot of collector area. The addition of nanoparticles thus at least partially counters the effect of the lower conductivity of the collector materials.

[0038] Other arrangements are possible. For example, if it is desired to use a system similar to system **600** to heat domestic hot water (DHW), then the heat transfer fluid circulated through the collector may be isolated from the domestic hot water tank, using a heat exchanger to transfer heat to the domestic hot water tank. An example of such a system **700** is shown in **FIG. 7**. Several components of system **700** are similar to components in system **600**, and are given like reference numerals in FIG. 7. System **700** includes a heat exchanger **701** to isolate the heat transfer fluid that flows through collector **500** from domestic hot water **702** in tank **603**. Also, electrodes **611** of ion generator **610** are positioned in pipe **605**, rather than in tank **603**. Finally, a drainback tank **703** is provided, so the heat transfer fluid circulating to collector **500** can drain completely back into the conditioned space in times of freezing weather. Alternatively, the heat transfer fluid flowing through collector **500** could be treated with an anti-freeze additive, in which case the closed loop could be completely filled and not drain back tank would be necessary.

[0039] Another phenomenon that may be of particular interest in a plastic solar collector is stagnation of the collector. Stagnation refers to the condition where the heat transfer fluid is not circulating through the collector, but the collector is in sunlight. This situation may occur, for example, if tank **603** has reached its desired temperature and controller **608** shuts off pump, even though collector **500** is at a higher temperature than tank **603**. Without the circulating heat transfer fluid to carry heat away from collector **500**, collector **500** may reach such high temperatures that collector **500** may be damaged.

[0040] In conventional systems having collectors made of metal parts, simply draining back the heat transfer fluid may be sufficient to provide adequate protection, as the metal parts may be able to withstand the temperatures reached by the empty collector. However, the plastic materials used in a collector according to embodiments of the invention may have a relatively low melting temperatures, and may be subject to thermal expansion and warping whether filled or empty.

[0041] In some embodiments, protection from damage due to stagnation may be provided by circulating a cooling fluid through the collector when the storage tank is at its full temperature, but the collector is in sunlight. **FIG. 8** illustrates a system **800** that uses a ground coupled heat exchanger in the form of piping loop **801** to provide cooling fluid to collector **500**, in accordance with embodiments of the invention. Ground coupled piping loop **801** may be, for example, a length of plastic pipe buried in a trench a few feet deep, packed with sand, and covered with earth. The temperature of soil underground tends to remain very stable throughout the year, typically about 57 °F in many parts of the United States. The earth can therefore act as a large heat source or heat sink. When fluid is circulated through piping loop **801**, the fluid gains heat from the ground if the fluid enters piping loop **801** at a temperature colder than the ground or gives up heat to the ground if the fluid enters piping loop **801** at a temperature warmer than the ground. Techniques for constructing piping loop **801** are given in U.S. Provisional Patent Application No. 61/680,671 previously incorporated by reference.

[0042] In system **800**, controller **608** monitors the temperature of heat transfer fluid **602** in tank **603**, and also the temperature of collector **500**. When stagnation is detected, for example when tank **603** is at its maximum desired temperature and collector **500** exceeds a safe operating temperature, controller **608** enters a stagnation remediation mode. In one example embodiment, controller **608** may enter the stagnation remediation mode when collector **500** exceeds 120 °F, although other criteria may be used.

[0043] In the stagnation remediation mode, circulation pump **604** is shut off. Preferably after a short delay, two normally-open valves **802** and **803** are switched closed under control of controller **608**, to isolate tank **603**. Second pump **804** is then started. Piping loop **801** has been previously filled with water, so that water is drawn by second pump **804** from piping loop **801**, travels up pipe **605** to collector **500** where it is heated and cools the collector, and travels down pipe **606**. Because normally-open valve **802** is closed, the water travels through pipe **805** back to piping loop **801** to give up heat and circulate for another cycle through collector **500** if needed. It is envisioned that only a few minutes of cooling will be required at any one time to bring collector **500** back to a safe temperature, and that the energy consumption of second pump **804** and valves **802** and **803** will therefore be small.

[0044] For added security, an additional, redundant pump **806** may be installed in parallel with second pump **804**. Controller **608** may sense whether pump **804** is operating properly and if not, redundant pump **806** would be started, to ensure that collector **500** is properly cooled. In some embodiments, emergency battery power could be used to operate the system during power outages.

[0045] In other embodiments, for example for installations where it is not possible to install a collector in such a way that it can drain back completely, the stagnation remediation mode may also be used for freeze protection. That is, heat transfer fluid could be circulated through piping loop **801** and through the collector in times of freezing temperatures. Instead of cooling the collector to prevent damage from stagnation, the circulating fluid would be heated by the ground loop and would warm the collector to prevent damage from freezing. In some embodiments, no additional hardware would be necessary. The additional control logic could simply be programmed into controller **608**.

[0046] While controller **608** is described above as being programmable, the system may also be implemented by a set of temperature sensors and logical connections between them, without requiring a programmable element such as a microprocessor. For example, a differential temperature sensor may compare the temperatures of the collector and tank, and generate a logic level indicating whether the collector is warmer or cooler than the tank. That signal would be routed to a drive circuit for circulation pump **604**, and circulation pump **604** would run when the collector is warmer than the tank, but would not run otherwise. The drive signal could be further gated by other logic signals. For example, another differential sensor could compare the tank temperature to a desired upper limit value, and generate a logic level indicating whether the tank is at the desired temperature or not. If so, the drive signal to circulation pump **604** could be overridden so that circulation pump **604** would not run in this state. Other gating signals would be derived to indicate stagnation (collector above a stagnation limit temperature), freeze danger (collector below a threshold temperature), or other conditions. It is intended that the term "controller" encompass both programmable devices and control logic implemented by discrete components.

[0047] In one example embodiment, controller **608** may be programmed or otherwise configured to implement the following control scheme:

Condition	Pump 604	Pump 804	Pump 806	Valves 802 and 803	Comment
a) tank below desired temperature b) collector temperature higher than tank temperature c) collector temperature below stagnation temperature	On	Off	Off	Open	Normal heating operation
a) tank below desired temperature b) collector not warmer than tank c) collector not in danger of freezing	Off	Off	Off	Open	Normal operation, wait for collector to warm up
a) tank at desired temperature b) collector below stagnation temperature c) collector above freezing	Off	Off	Off	Open	Normal operation when heat not needed
a) collector at or above stagnation temperature b) pump 804 working	Off	On	Off	Closed	Stagnation remediation
a) collector at or above stagnation temperature b) pump 804 not working	Off	X	On	Closed	Stagnation remediation using redundant pump

a) collector in danger of freezing b) pump 804 working	Off	On	Off	Closed	Freeze protection using stagnation remediation mode
a) collector in danger of freezing b) pump 804 not working	Off	X	On	Closed	Freeze protection using stagnation remediation mode, redundant pump

[0048] While collector **500** shown in FIGS. 5-8 is in a rectangular configuration, the invention is not so limited, and it will be appreciated that the construction techniques and materials described above provide opportunities for configuration and customization of collectors, and may enable use of solar collectors in locations that were not previously convenient.

[0049] For example, **FIG. 9** shows a collector **900** in accordance with another embodiment of the invention. Collector **900** includes a single elongate receiving tube **901** surrounded by a sheath **902**. Receiving tube **901** may be made from a continuous plastic pipe, or may include splices. Similarly, sheath **902** may also include splices, and periodic spacers **903** may be used to maintain space between receiving tube **901** and sheath **902** if desired. Sheath **902** also preferably includes a reflective coating **904** on one side, to enhance the collection efficiency of collector **900**, as described above. Collector **900** is depicted as being about 1.5 inches in diameter and about eight feet long, but the length of the collector is limited only by the practicality of installing it and the ability to pump heat transfer fluid through the narrow receiving tube for long distances. For example, collector **900** may have length as much as 50, 100, 200, 500, or more times its width. The ratio of the collector's length to its width may be called the collector's aspect ratio.

[0050] A collector such as collector **900** or another collector according to embodiments of the invention may be installed in places where a conventional collector panel could not. For example, collector **900** may be installed on top of a fence or wall, on a building ledge, on a building eave, or in another location that has good sun exposure but would not be convenient for mounting another kind of collector, for example a traditional flat panel collector having an aspect ratio of about 2:1. Collector **900** may be somewhat flexible, and could include right-angle or other angular bends through the use of simple and readily available fittings. Thus, solar energy may be utilized in an unobtrusive manner.

[0051] It may be especially helpful for such a system to include the stagnation remediation capability described above and shown in FIG. 8. A long narrow collector installed on top of a wall would likely not be configured to drain completely by gravity. The stagnation remediation mode may be especially useful with such an installation to avoid freezing on winter nights, for example.

[0052] Many other collector configurations are possible as well. For example, long narrow collectors having two, three, four, or another number of parallel receiving tubes and sheaths could be used, depending on the size and shape of the area available for mounting the collector. Such collectors may have aspect ratios much larger than the typical conventional flat panel collector, for example 3:1, 4:1, 5:1, 10:1, 20:1, 50:1, 100:1, 200:1, 500:1, or another aspect ratio, and may be installed in spaces that could not accommodate a collector of equal area having a significantly smaller aspect ratio. For the purposes of this disclosure, a significantly smaller aspect ratio is any aspect ratio less than about 50 percent of the aspect ratio of the collector in question.

[0053] As was mentioned earlier, one application of a solar energy collection system according to embodiments of the invention is root zone heating of plants. Research has shown that heating the soil in the root zone of plants can promote improved growth and productivity of the plants, and enables cultivation of plant species in much colder ambient environments than the plants' native environments. **FIG. 10** illustrates a solar energy collection system **1000**, adapted for root zone heating. Solar energy collection system **1000** is illustrated as similar to system **600** shown in FIG. 6, with the addition of a root zone heating loop **1001**. A root zone heating pump **1002**, under control of controller **608**, circulates heat transfer fluid **602** from tank **603** through root zone heating loop **1001**, delivering heat to roots **1003** of plants **1004**. Controller **608** may control pump **1002** intermittently, for example on a fixed schedule, or based on the relative temperatures of tank **603** and the soil beneath plants **1004**. Although not shown, root zone heating loop **1001** may be used in conjunction with stagnation remediation measures, for example as shown in FIG. 8.

[0054] The invention has now been described in detail for the purposes of clarity and understanding. However, it will be appreciated that certain changes and modifications may be practiced within the scope of the appended claims. It is intended that all workable combinations of the elements and features described herein are also considered to be disclosed.

WHAT IS CLAIMED IS:

1. A solar energy collector, comprising:

an elongate plastic receiving tube configured to carry a heat transfer fluid;

an elongate clear plastic tubular sheath surrounding the receiving tube, the sheath being of a larger cross section than the receiving tube such that a generally annular air space is formed between the receiving tube and the sheath, the sheath having a front side configured to be disposed toward the sun and a back side opposite the front side; and

a reflective coating partially covering a portion of the inside surface of the tubular sheath at the back side of the tubular sheath and configured such that when sunlight is directed at the front side of the sheath, a first portion of the sunlight transmitted through the sheath strikes the receiving tube directly, and a second portion of the sunlight transmitted through the sheath strikes the reflective coating and is redirected to the receiving tube.

2. The solar energy collector of claim 1, wherein the receiving tube is made of black polyethylene tubing.

3. The solar energy collector of claim 1, wherein the sheath is made of clear polycarbonate tubing.

4. The solar energy collector of claim 1, wherein both the receiving tube and the sheath have circular cross sections.

5. A solar energy collector, comprising:

a plurality of elongate plastic receiving tubes configured to carry a heat transfer fluid;

a plurality of elongate clear plastic tubular sheaths, each sheath surrounding a respective one of the plurality of receiving tubes, each sheath being of a larger cross section than its respective receiving tube such that a generally annular air space is formed between sheath and the receiving tube, each sheath having a front side configured to be disposed toward the sun and a back side opposite the front side, wherein a portion of the interior surface of the sheath at the back side is covered by a reflective coating configured such that when sunlight is directed to the uncoated portion of the sheath, a first portion of the sunlight transmitted through the sheath strikes the receiving tube directly and second portion of the sunlight transmitted through the sheath strikes the reflective coating and is redirected to the receiving tube;

an inlet manifold including an inlet opening for receiving the heat transfer fluid to be heated and a plurality of outlet openings; and

an outlet manifold including a plurality of inlet openings and an outlet opening;

wherein each of the plurality of receiving tubes is coupled between one of the plurality of outlet openings of the inlet manifold and one of the plurality of inlet openings of the outlet manifold.

6. The solar energy collector of claim 5, wherein the inlet and outlet manifolds are made of plastic.

7. The solar energy collector of claim 5, wherein the plurality of receiving tubes are disposed parallel to each other to form a rectangular collector unit.

8. The solar energy collector of claim 7, wherein:

the inlet manifold, the outlet manifold, the plurality of receiving tubes, and the plurality of sheaths are comprised in a first collector unit; and

the solar energy collector comprises one or more additional collector units of like construction to the first collector unit, the inlet manifolds of the one or more additional collector units operatively coupled to the inlet manifold of the first collector unit and the outlet manifolds of the one or more additional collector units operatively coupled to the outlet manifold of the first collector unit.

9. The solar energy collector of claim 7, wherein gaps exist between adjacent members of the plurality of sheaths.

10. The solar energy collector of claim 7, wherein the solar energy collector has an aspect ratio of at least 3:1.

11. The solar energy collector of claim 7, wherein the solar energy collector has an aspect ratio of at least 5:1.

12. A solar energy collection system, comprising:

a solar energy collector comprising an elongate plastic receiving tube surrounded by an elongate clear plastic sheath, the sheath being of a larger cross section than the receiving tube such that a generally annular air space is formed between the receiving tube and the sheath, the sheath having a front side configured to be disposed toward the sun and a back side opposite the front side and a reflective coating partially covering a portion of the inside surface of the tubular sheath at the back side such that when sunlight is directed at the front side of the sheath, a first portion of the sunlight transmitted through the sheath strikes the receiving tube directly, and a second portion of the sunlight transmitted through the sheath strikes the reflective coating and is redirected to the receiving tube; and

a supply of the heat transfer fluid to be heated by the solar energy collector.

13. The solar energy collection system of claim 12, wherein:

the solar energy collector comprises a plurality of elongate plastic receiving tubes, each surrounded by a respective elongate clear plastic sheath;

the plurality of sheaths and receiving tubes are arranged in parallel such that the solar energy collector is rectangular; and

the solar energy collector comprises an inlet manifold and an outlet manifold to direct the heat transfer fluid through the parallel receiving tubes.

14. The solar energy collection system of claim 12, wherein the heat transfer fluid is water comprising nanoparticles.

15. The solar energy collection system of claim 14, further comprising an ion generator to generate the nanoparticles.

16. The solar energy collection system of claim 12, further comprising:

a tank for holding the supply of heat transfer fluid;

a supply pipe for carrying heat transfer fluid from the tank to the solar energy collector;

a return pipe for carrying the heat transfer fluid from the solar energy collector to the tank;

a circulation pump for circulating the heat transfer fluid between the solar energy collector and the tank through the supply pile and the return pipe; and a controller that controls the operation of the circulation pump based at least in part on the temperature of the heat transfer fluid in the tank and the temperature of the solar energy collector.

17. The solar energy collection system of claim 16, wherein the controller is configured to determine when the solar energy collector reaches a stagnation condition and in response to the determination, enter a stagnation remediation mode.

18. The solar energy collection system of claim 17, further comprising a source of cooling fluid, wherein during the stagnation remediation mode, the cooling fluid is circulated through the solar energy collector without passing through the tank.

19. The solar energy collection system of claim 17, further comprising a ground coupled heat exchanger, wherein in the stagnation remediation mode, the cooling fluid is circulated through the solar energy collector and the ground coupled heat exchanger without passing through the tank.

20. The solar energy collection system of claim 19, wherein the ground coupled heat exchanger comprises a piping loop connected between the supply pipe and the return pipe, and wherein the system further comprises a set of valves operated by the controller to isolate the tank during the stagnation remediation mode.

21. The solar energy collection system of claim 16, further comprising a photovoltaic panel that supplies power to operate the controller and the circulation pump.

22. The solar energy collection system of claim 16, further comprising a root zone heating loop, wherein the system circulates the heat transfer fluid through the root zone heating loop to heat the root zone of plants.

23. A method of collecting solar energy, the method comprising:

providing a solar energy collector comprising one or more elongate plastic receiving tubes each surrounded by a respective elongate clear plastic sheath, each respective sheath being of a larger cross section than its respective receiving tube such that a generally annular air space is formed between the receiving tube and the sheath, the sheath having a front side configured to be disposed toward the sun and a back side opposite the front side and a reflective coating partially covering a portion of the inside surface of the tubular sheath at the back side such that when sunlight is directed at the front side of the sheath, a first portion of the sunlight transmitted through the sheath strikes the receiving tube directly, and a second portion of the sunlight transmitted through the sheath strikes the reflective coating and is redirected to the receiving tube;

installing the solar energy collector in a location that receives sunlight; and

passing a heat transfer fluid through the solar energy collector to be heated by the sunlight.

24. The method of claim 23, wherein the solar energy collector has an aspect ratio of at least 3:1, and wherein installing the solar energy collector in a location that receives sunlight comprises installing the solar energy collector in a location that cannot accommodate a collector of equal area having a significantly smaller aspect ratio.

25. The method of claim 23, wherein the solar energy collector has an aspect ratio of at least 5:1, and wherein installing the solar energy collector in a location that receives sunlight comprises installing the solar energy collector in a location that cannot accommodate a collector of equal area having a significantly smaller aspect ratio.

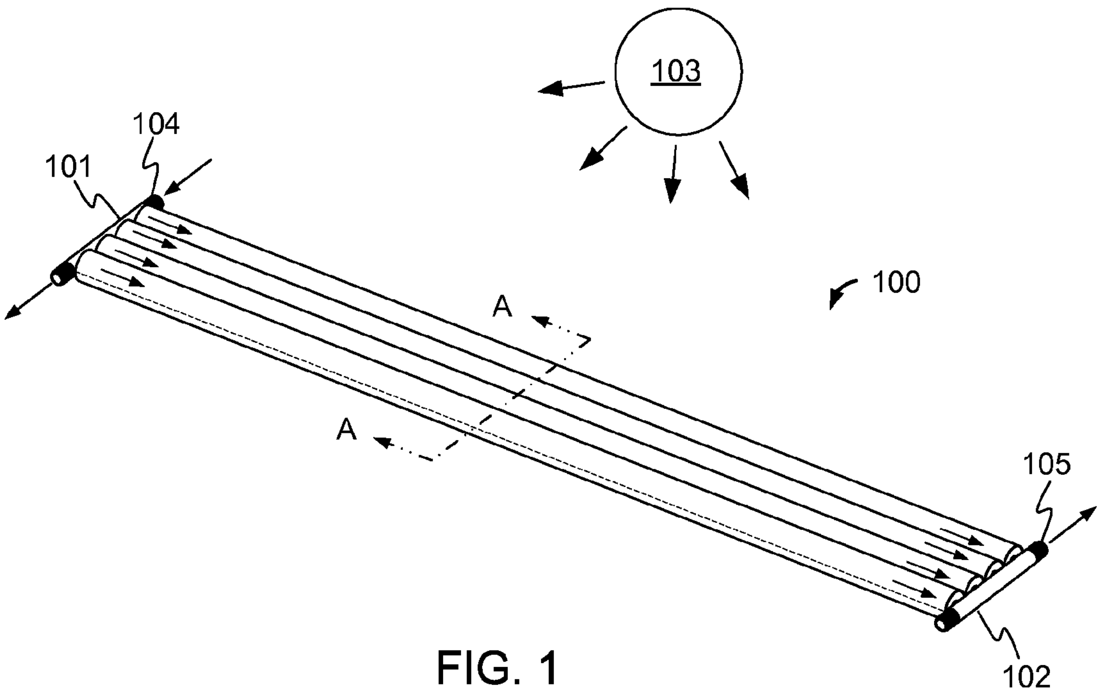
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FIG. 1

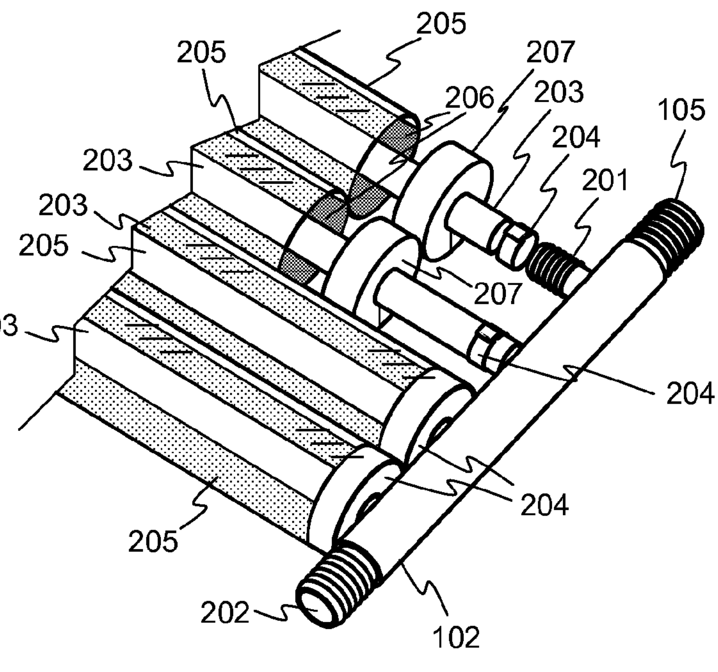
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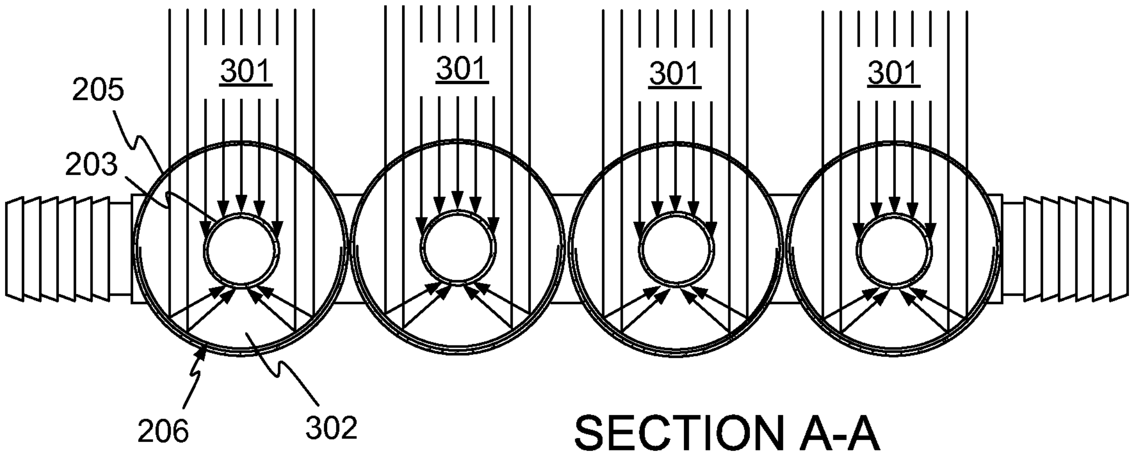
FIG. 2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SECTION A-A

FIG. 3

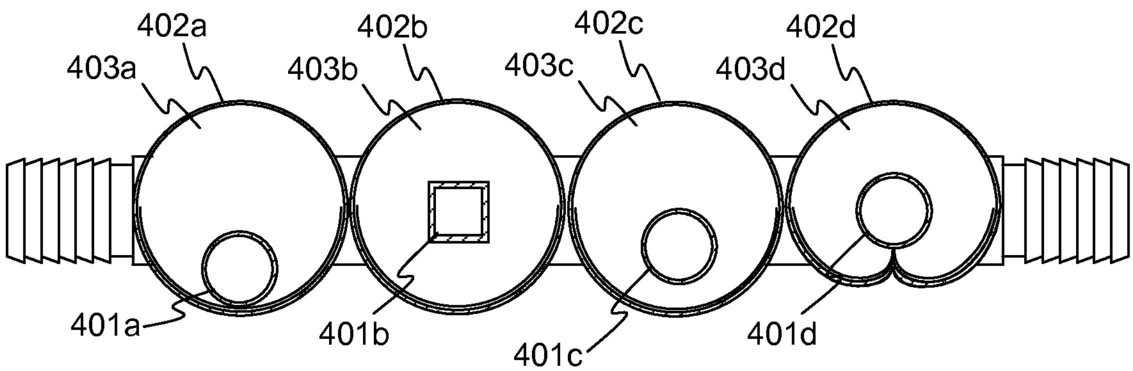
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FIG. 4

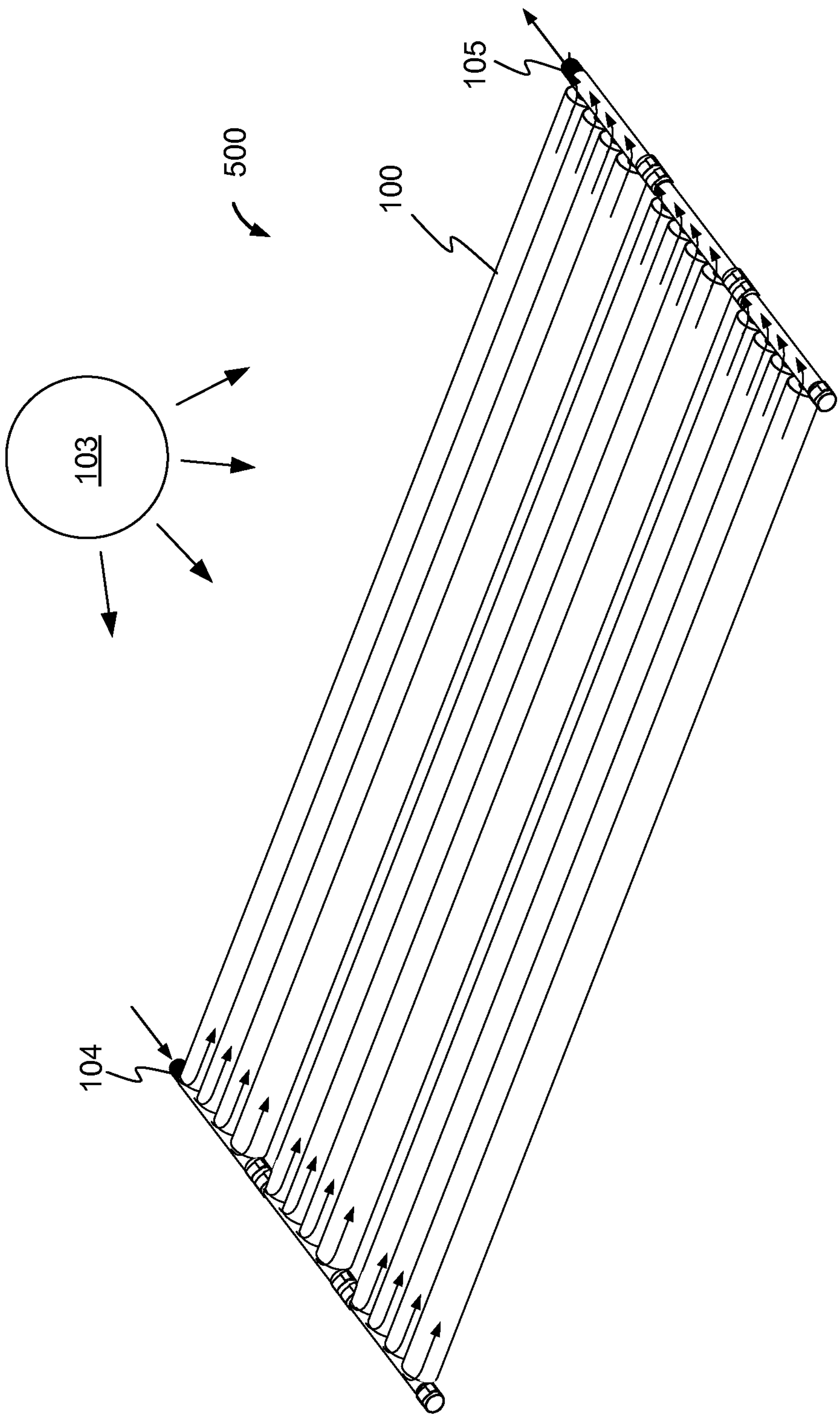
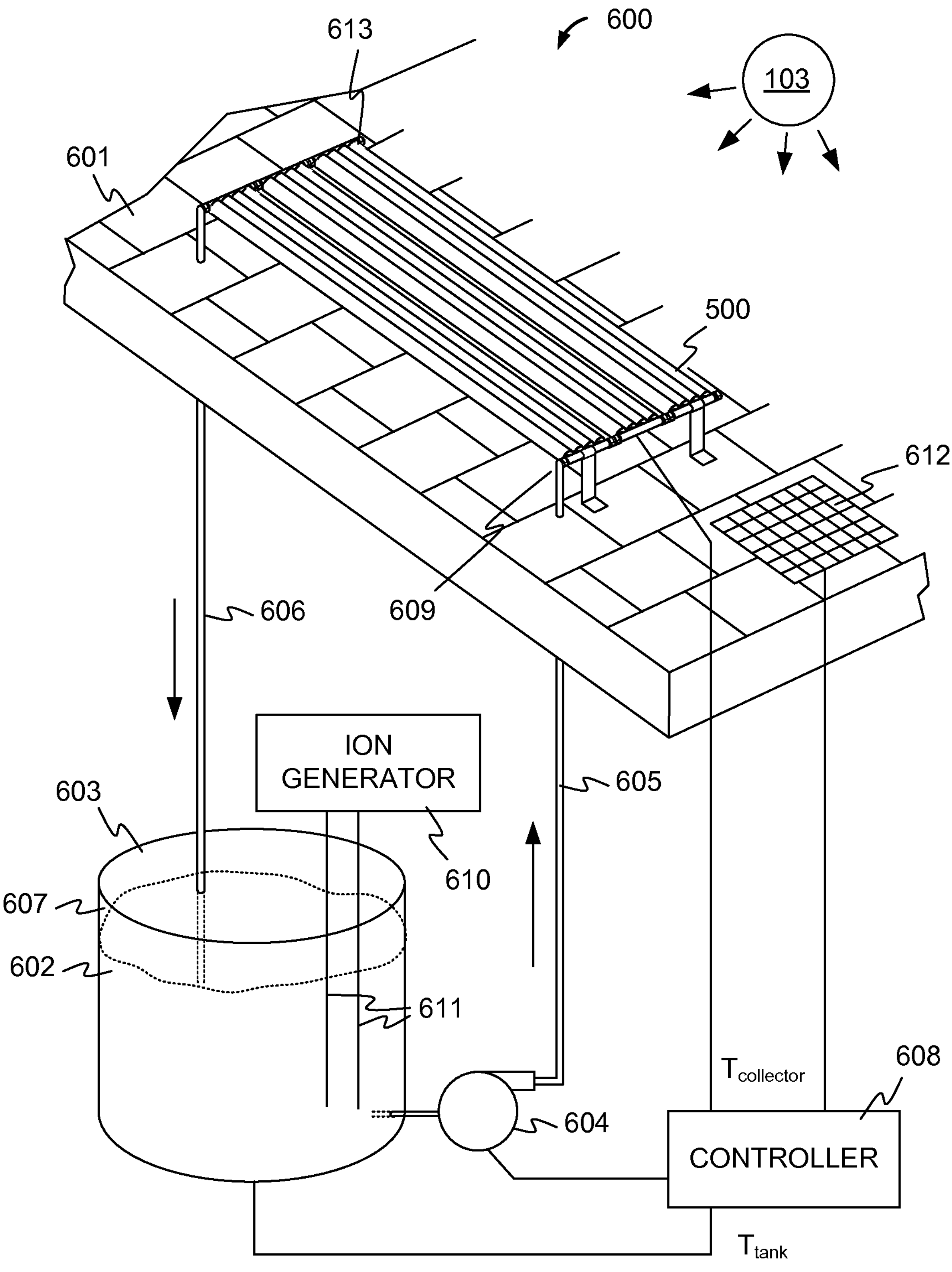


FIG. 5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500
612
606
609
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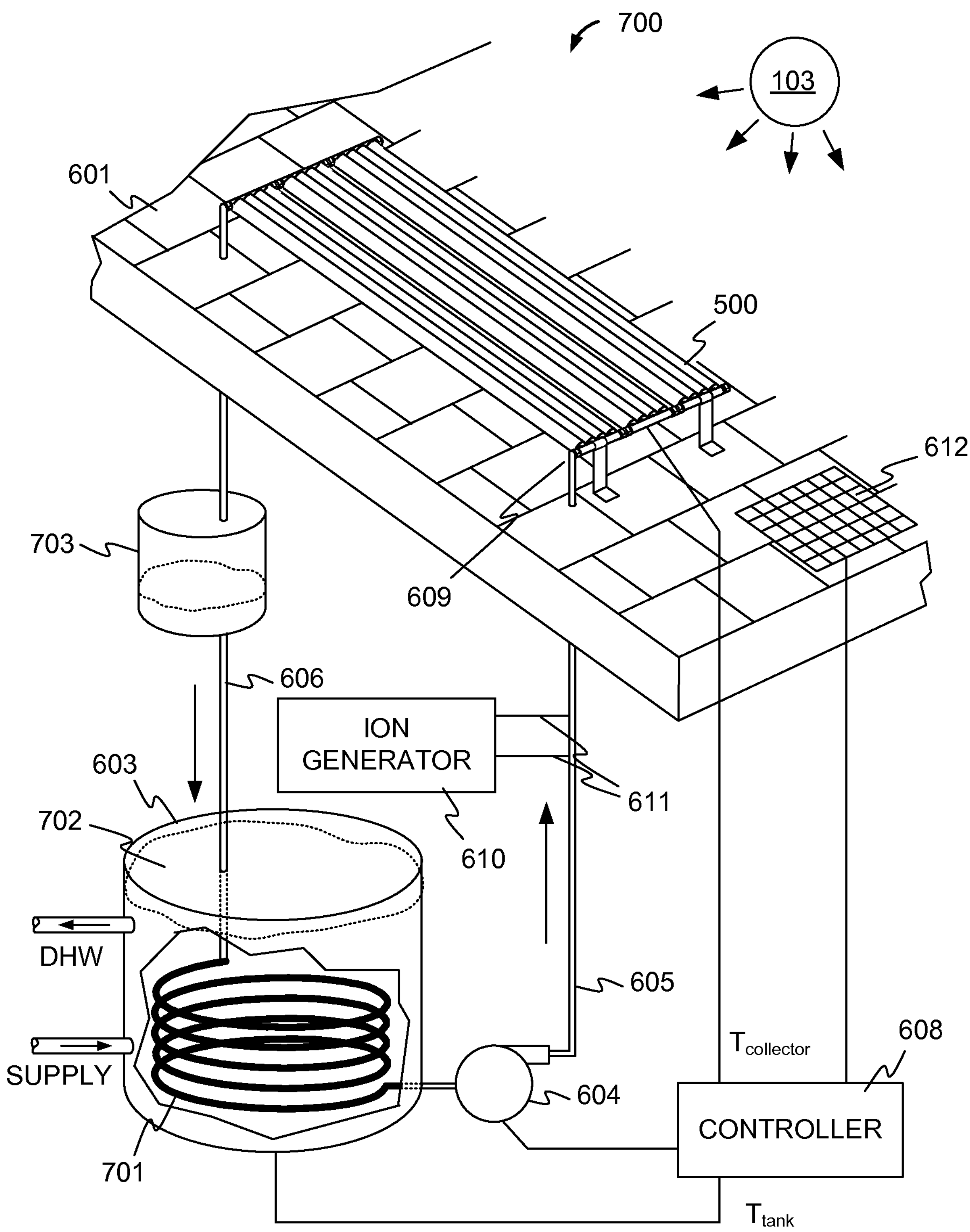
CONTROLLER
T_{tank}

FIG. 6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CONTROLLER
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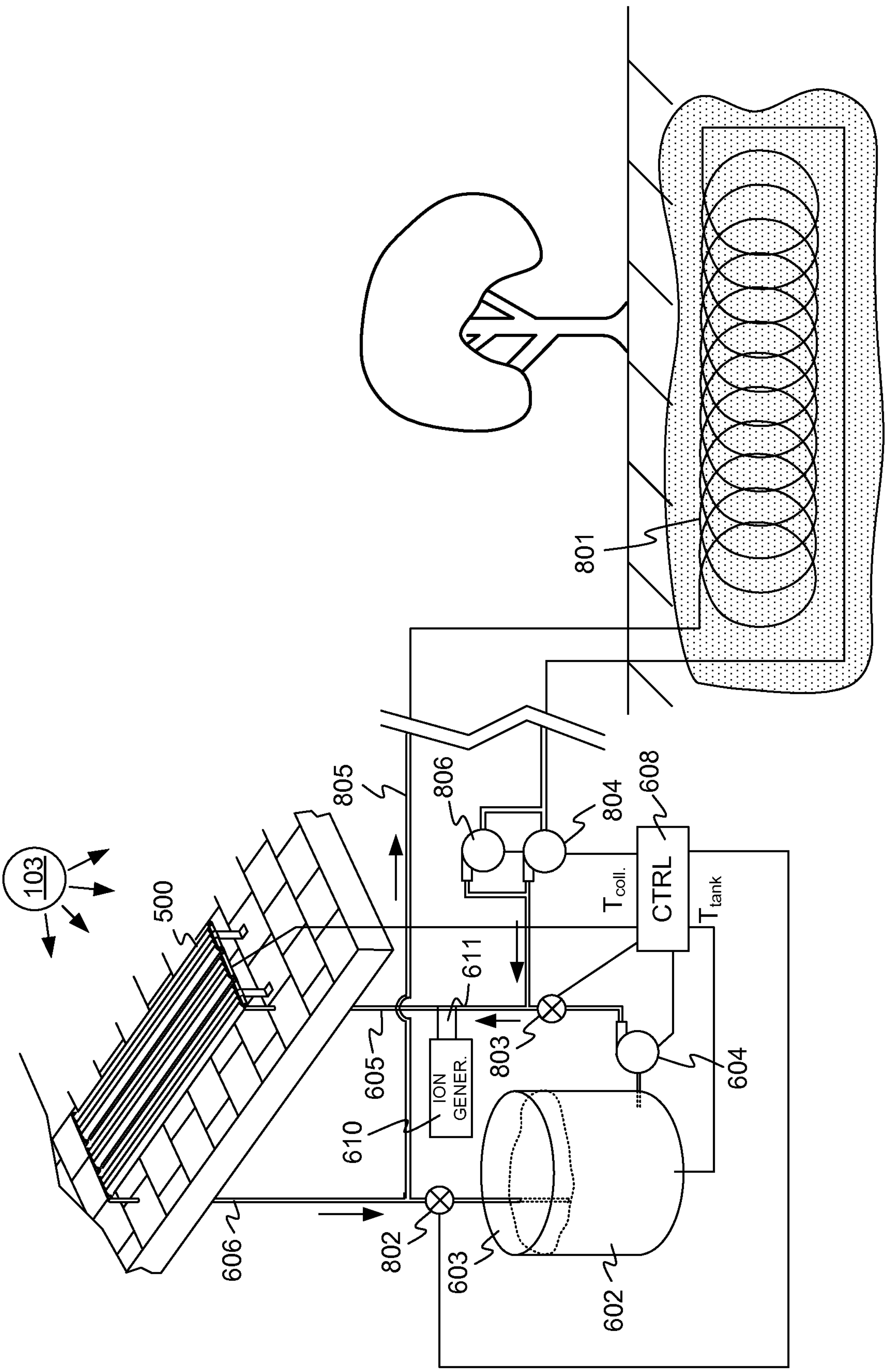
T_{tank}

FIG. 7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801

FIG. 8

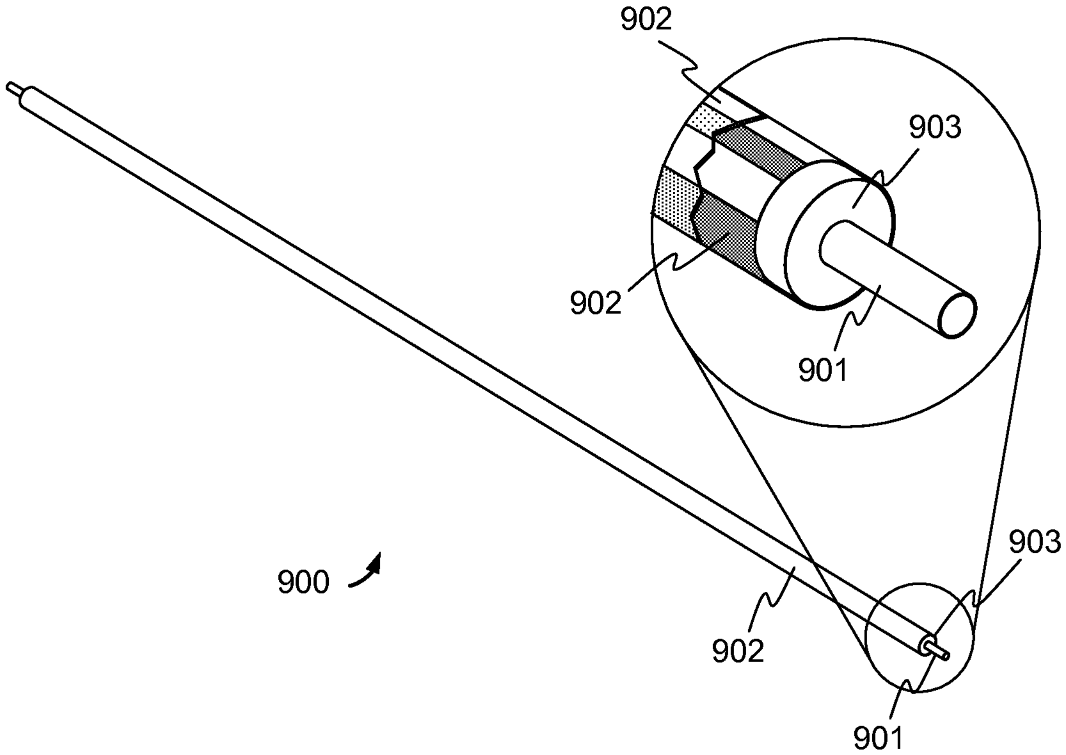
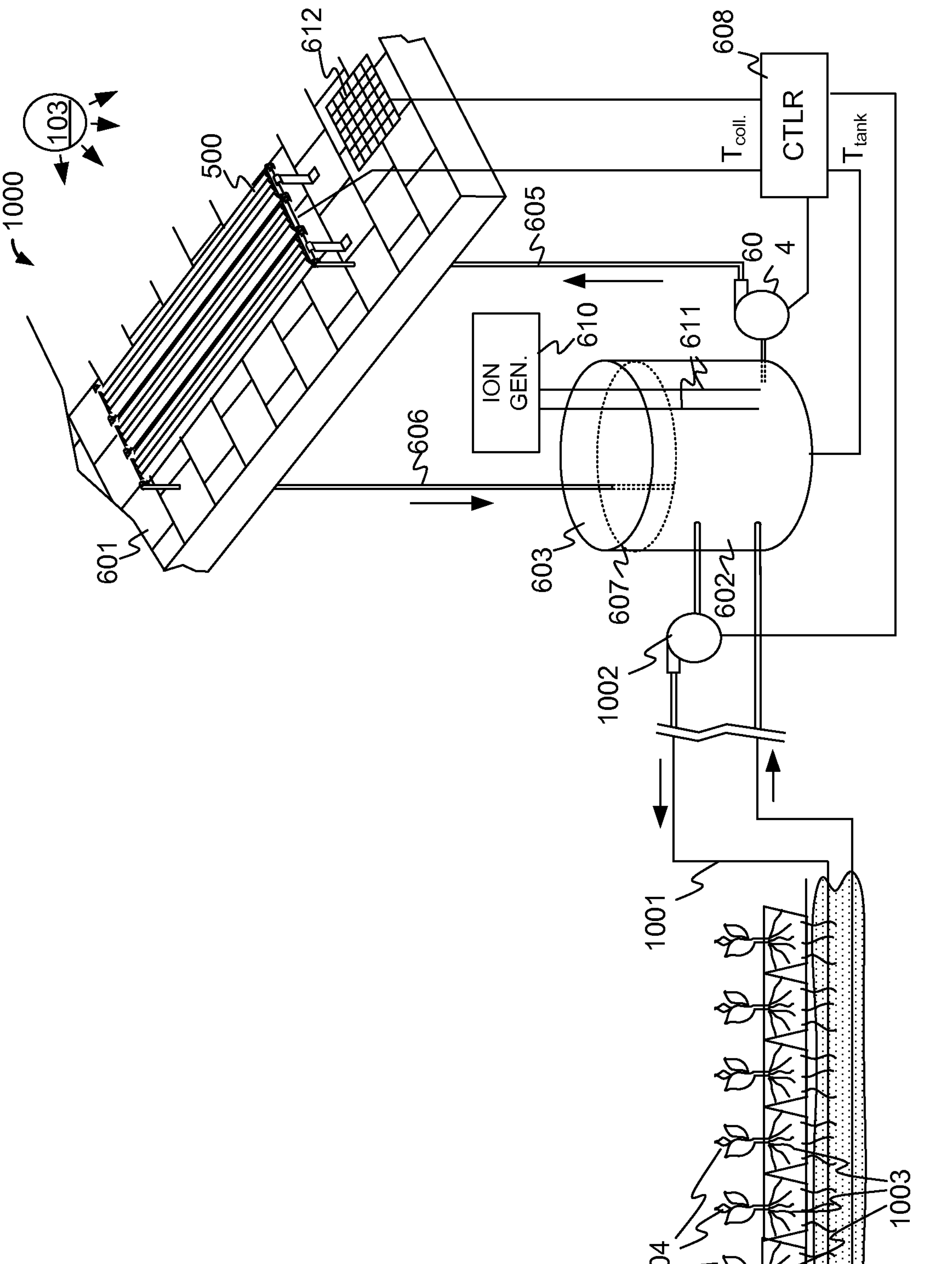


FIG. 9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1002
1001
1004
1003

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/031337

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F16L 9/14 (2014.01)
USPC - 126/569
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B29C 47/04; B29D 23/00; F16L 9/14, 9/18, 11/04; F24J 2/00, 2/05, 2/24, 2/46, 2/48 (2014.01)
USPC - 126/569, 589, 636, 652, 655, 663, 676, 677, 907; 136/246

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - B29C 47/04; B29D 23/00; F16L 9/14, 9/18, 11/04; F24J 2/00, 2/05, 2/24, 2/46, 2/48 (2014.07)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Orbit, Google Patents, Google, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 048 459 A (GUNDERSON) 10 December 1980 (10.12.1980) entire document	1-4, 12, 16, 17, 23-25
Y		5-7, 9-11, 13-15, 18-21
Y	WO 2012/040778 A1 (MILLS) 05 April 2012 (05.04.2012) entire document	5-7, 9-11, 13
Y	CN 201488320 U (GU) 26 May 2010 (26.05.2010) see machine translation	14, 15
Y	US 4,528,976 A (BAER) 16 July 1985 (16.07.1985) entire document	18-21

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 July 2014	20 AUG 2014

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774